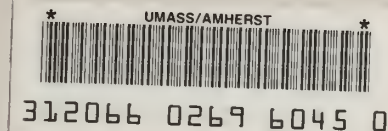
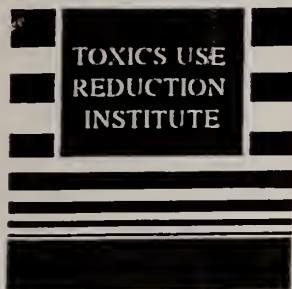


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Toxics Use Reduction Institute Research Program

1990-1997

February 1997

University of Massachusetts Lowell

Toxics Use Reduction Institute Research Program 1990-1997

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**The Toxics Use Reduction Institute
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1997



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The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989. The Institute sponsors and conducts research, organizes education and training programs, and provides technical support to promote the reduction in the use of toxic chemicals or the generation of toxic chemical byproducts in industry and commerce. Further information can be obtained by writing the Toxics Use Reduction Institute, University of Massachusetts Lowell, One University Avenue, Lowell, Massachusetts 01854.

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SUMMARY

During the past seven years the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell has carried out a wide range of technical, methodological, and policy research in support of the Commonwealth's commitment to prevent pollution through toxics use reduction. Much of this has been accomplished in close collaboration with other state agencies, educational institutions, and some of the most innovative firms in Massachusetts. This research has resulted in technologies, materials and procedures which reduce the use of toxic chemicals or the generation of toxic wastes while enhancing the economic viability of Massachusetts firms.

The Research Program

Mission

The Toxics Use Reduction Institute's research program has facilitated the adoption of toxics use reduction in Massachusetts through:

- **research** on toxics use reduction technologies, processes and materials
- **development** of methods for use by industry to integrate toxics use reduction into processes and products, and public policies that promote toxics use reduction
- **transfer** of toxics use reduction technologies from researchers to manufacturing and service sectors

Priorities

The Institute gives priority to research that:

- is mandated by the Massachusetts Toxics Use Reduction Act of 1989
- was identified as a priority by industry focus groups
- meets a need as identified by the TURA data or the Toxics Release Inventory data
- addresses extremely hazardous chemicals, chemicals whose use is restricted by federal regulations, and industries with great potential for toxics use reduction



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Highlights

TURI's Surface Cleaning Lab is making *cleaning greener* in *Massachusetts*.

In 1993 the Institute established a special Surface Cleaning Laboratory to help Massachusetts metalworking, electronics, computer and automotive manufacturers find environmentally sound alternatives to hazardous industrial cleaning processes. Of companies assisted to date with completed projects, 80% have either switched from toxic solvents to water-based solvents or were helped to overcome problems with their water-based systems.

A.W. Chesterton, Groveland, Mass.
manufacturer of epoxy resins and curing agents

Before:

Used a mixture of hazardous solvents - methanol, xylene and methyl ethyl ketone - for cleaning resin mixing equipment

After:

Switched to water-based cleaning using manual scrubbing and low-pressure spray equipment

TURI advances innovation in toxics use reduction technologies and....

Since 1992, the Institute's Industry Matching Grants Program has supported the development and implementation of innovative toxics use reduction technologies in 24 companies with awards totaling \$266,000.

In 1995, the Institute began an unprecedented Cleaner Technology Demonstration Sites Program to enable Massachusetts innovators to open their doors to other local manufacturers and the public. This program attracted over 500 visitors to 25 site visits at 5 companies.

spreads the word to potential adopters.

Printed Circuit Corp., Woburn, Mass:

Printed Circuit Corp., a manufacturer of printed wiring boards, received a \$15,000 Industry Matching Grant from the Institute to implement in-process recycling of nitric acid solder strip. As a result, the company's nitric acid use dropped by 74%.

TURI is spearheading an effort to take a hard look at progress under TURA.

In 1995 the Institute spearheaded a program-wide performance evaluation of the Toxics Use Reduction Program. The evaluation report, completed in early 1997, includes the results of:

- an assessment of whether the TURA agencies have fulfilled the mandates in the Act
- TURA data analysis
- a survey of TURA filers
- an in-depth investigation of 25 TURA filers
- a cost/benefit analysis of the TURA Program

TURI's InTURnship Program helps Massachusetts companies implement TUR....

The Institute kicked-off a Summer InTURnship Program in 1996, placing four students in Massachusetts companies in need of assistance with toxics use reduction implementation. The companies benefitted from the trained interns and the students enriched their education with work experience in industry.

Acushnet Rubber Company, New Bedford, Mass.

and students get valuable experience.

This manufacturer of rubber products hired an Institute intern to assist Acushnet in gaining the ISO 14001 international environmental management certification. The company became the first in Massachusetts and the fifth in the United States to become certified.

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I. Introduction

Since its inception in 1990, the Institute has facilitated the adoption of toxics use reduction in Massachusetts through a program of research, development and technology transfer. This report describes these activities and accomplishments. The report is divided into three sections. The first is a general introduction to the Institute's research program and describes the Institute's goals and approaches. The second section highlights the research program's current initiatives. The third section is a summary of major work performed under the Institute's research program from its inception in 1990. Additional detail is provided in appendices.

A. Goals

The broad goal of the Institute's research program is to facilitate the implementation of toxics use reduction techniques in Massachusetts. Specific research goals are:

- to perform and sponsor research on toxics use reduction technologies, processes and materials that aim at both short- and long-term solutions
- to perform research on toxics use reduction methods and policies that can be used by industry or government to foster the successful implementation of toxics use reduction techniques
- to transfer toxics use reduction technologies from the research community to the manufacturing and service communities.

To achieve these goals, research at the Institute encompasses three areas: **technical, methods and policy research.**

- Technical research explores the technical feasibility of specific toxics use reduction technologies, processes, and materials, and facilitates the transfer of these technologies to industry.
- Methods research develops and examines tools that industry and public agencies can use to measure, promote, plan, and assess toxics use reduction techniques.
- Policy research assesses, develops, and evaluates specific initiatives that public agencies can implement to reduce the use of toxic chemicals and the generation of toxic byproducts by industry.

B. Setting Priorities

The Institute has established priorities for its research work using several criteria. The following is a list of those criteria, with an example given for each.

- Mandated by the Toxics Use Reduction Act
 - e.g., support of the Science Advisory Board
- Identified as a priority by industry focus groups or other Toxics Use Reduction Program agencies
 - e.g., establishment of the Surface Cleaning Laboratory
- Need identified through evaluation of state Toxics Use Reduction data or federal Toxics Release Inventory data
 - e.g., research report on styrene
- Extremely hazardous or high risk chemicals
 - e.g., use of perchloroethylene in garment dry cleaning
- Regulatory restrictions or phase-outs
 - e.g., alternatives to ozone depleting substances
- Industries or processes with large toxics use reduction potential
 - e.g., electronics and metal finishing industries

II. Current Research Initiatives

The Institute's research priorities have given rise to a number of focus areas. The following initiatives are designed to target resources toward those areas. Current activities for those initiatives are described in this section. More detailed information is included in Section III and the Appendix.

- Surface Cleaning
- Industry Sector Initiatives:
 - Electronics Industry - Printed Wiring Board (PWB) Manufacture
 - Metal Fabrication and Finishing
- TURA Program Evaluation
- Cleaner Technology Demonstration Sites and Industry Matching Grants Program
- University Programs
 - Summer InTURnship Program
 - Research Fellows Program
- Toxics Use Reduction Science Advisory Board
- Sustainable Production Methods

Surface Cleaning

Surface cleaning is a critical process in electronics, metal finishing and other key manufacturing industries in Massachusetts. The Institute's Surface Cleaning Program provides information and assistance to Massachusetts firms making the transition from chlorinated and organic cleaning solvents to aqueous alternatives. The cornerstone of the program is the Institute's state-of-the-art Surface Cleaning Laboratory.

☐ Surface Cleaning Laboratory

The Surface Cleaning Laboratory, in operation since 1994, is uniquely equipped to evaluate the effectiveness of aqueous and semi-aqueous chemistries and cleaning equipment on the wide variety of industrial parts and soils found in Massachusetts companies. The Surface Cleaning Lab offers its services at no cost to Massachusetts industries.

- Of the first 20 companies assisted, 13 have switched from hazardous solvents to aqueous or semi-aqueous processes and 3 solved problems in their existing aqueous systems.
- At present, 17 companies are in process, i.e., in preliminary test design, lab testing, or field implementation.

"Give Us... Your Dirty Parts"

The Surface Cleaning Lab gets greasy, grimy industrial parts from Massachusetts manufacturers seeking safer cleaners. Using state-of-the-art methods, the Lab provides detailed recommendations on alternative chemistries and equipment.

☐ Technology Transfer

- The Institute has developed and published an extensive database of alternative cleaners and related equipment.
- The Institute disseminates information on innovative cleaning methods through workshops, fact sheets and journal articles. The Institute hosted the Mr. Clean Conference in 1996, a gathering of national experts on industrial cleaning.

Surface Cleaning Laboratory Case Studies

Market Forge, Everett

manufacturer of steel and aluminum boiler parts

Before:

Used trichloroethane to clean boiler parts in a vapor degreaser

After:

Installed a spray washer with low-foaming alkaline cleaner

A.W. Chesterton Co., Groveland

manufacturer of curing agents and resins for specialty adhesives market

Before:

Cleaned epoxy resins and curing agents off mixing blades with methanol and xylene/methyl ethyl ketone

After:

Installed a spray aqueous cleaning system combined with manual scrubbing

Industry Sector Initiatives

The Institute's Research Program has focused on two industrial sectors - electronics and metal fabrication and finishing.

☐ Electronics - Printed Wiring Board Manufacture

The electronics industry, and the manufacture of printed wiring boards (PWBs) in particular, has a strong presence in Massachusetts. While the Toxics Use Reduction Program data reveal that large quantities of toxic chemicals are currently used in these facilities, research indicates that there are many opportunities for toxics use reduction. The industry is receptive to change and innovation, and therefore has the potential to achieve significant toxics use reduction.

- The Institute is sponsoring research in no-clean soldering for PWB assembly and additive (vs. subtractive) techniques for creating circuits -- two critical technology developments for environmental improvements in electronics manufacturing.
- In 1997, the Institute will sponsor two Cleaner Technology Demonstration Sites at electronics manufacturing firms, enabling members of industry and the public to learn about innovative TUR technologies in Massachusetts electronics firms.
- The Institute has sponsored research in a number of innovative toxics use reduction technologies in the electronics industry, including: cupric chloride etch regeneration, aqueous cleaning, and in-process recycling of nitric acid solder strip.

☐ Metal Fabrication and Finishing

Many metal fabrication and finishing facilities in Massachusetts report using large quantities of toxic chemicals and many opportunities exist for toxics use reduction. The Institute's first focus group with the metal finishing industry in 1992 led to research on surface cleaning and non-cyanide plating. The current focus is on supply chain management of metalworking fluids and subsequent cleaning.

- The Institute prepared a fact sheet titled "Overview of Machining Fluids and Aqueous Cleaning with Pollution Prevention Opportunities."
- The Institute sponsored industry and university research on acid bath-life extension via diffusion dialysis and aqueous cleaner bath-life extension via membrane filtration. Reports on the results of the research were prepared.
- In 1997, the Institute plans to research dry machining and dry plating technologies and prepare fact sheets or reports, as appropriate.

TURA Program Evaluation

The administrating agencies of the Toxics Use Reduction Program are jointly developing a program evaluation which began in 1995 and will end in 1999. The evaluation is being spearheaded by the Toxics Use Reduction Institute.

□ Goals of the evaluation

- to fulfill the law's requirement that the program assess itself against the goal of 50% reduction in toxic waste by the year 1997
- to assess the program's performance on the other five non-quantitative goals of the Act
- to inform the public about the program's effectiveness
- to enable program improvements based on evaluation data

□ Components

The Toxics Use Reduction program evaluation will include a series of components that are currently being carried out. These include:

- Mandates fulfillment analysis - an assessment of whether the Program agencies have fulfilled the specific mandates contained in the Act
- Program data validation and analysis
- Survey of firms that complied with the Law
- An in-depth investigation of 25 Massachusetts firms
- A cost/benefit study

The results of these evaluation efforts were presented in a report in early 1997. The results of additional evaluation efforts, including the analysis of the 1997 Program data, will be presented in follow-up reports.

Measuring Progress in Toxics Use Reduction: TURA Data Analysis

An analysis of the 1990 through 1994 TURA data for a core group of facilities and chemicals shows the following:

30% reduction in byproduct generation

20% reduction in toxic chemical use

Quantities are normalized for changes in level of production. Additional information is included in Section III.

Cleaner Technology Demonstration Sites and Matching Grants

In its four year history, the Institute's Industry Matching Grants Program has funded feasibility studies and pilot tests of innovative cleaner technologies, leading to their adoption in a number of Massachusetts firms. The Cleaner Technology Demonstration Sites Program, initiated in 1995, has promoted the adoption of cleaner technologies by encouraging innovative Massachusetts companies to showcase their innovations for other manufacturers and the general public.

- The Institute has sponsored 23 Industry Matching Grants over its five year history, supporting the development and implementation of innovative toxics use reduction technologies in 24 companies with awards totaling \$266,000.
- In the first year of the Cleaner Technology Demonstration Sites Program, 500 visitors attended 25 site visits at five companies.

Participating Companies and Projects - FY '96 & '97

(full description available in Appendix)

FY '97

General Dynamics Defense Systems, Pittsfield
Design for Environment Workshops

Leach & Garner Company, General Findings Division, North Attleboro
Ammonia Reduction for Heat Treat Furnace Atmospheres

Ocean Spray Cranberries, Inc., Middleboro
Elimination of Cooling Tower Chemical Additives

Parlex Corporation, Methuen
Innovations in Toxics Use Reduction in Printed Wiring Board Manufacture

Tri-Star Technologies Company, Inc., Methuen
Cupric Chloride Etch Regeneration

FY '96

Cranston Print Works, Webster
TUR Through Process Improvement, Substitution, and Integral Recycling

Danaher Tool Group, Springfield
Nitric Acid Recovery Using Diffusion Dialysis

Lockheed Martin Defense Systems, Pittsfield
Closed-Loop Aqueous Cleaning of Mechanical Parts

Metallized Products, Inc., Winchester
Electron Beam Curing of Polymers in Coating Processes

Utopia Cleaners, Arlington
Garment Wet Cleaning

University Programs

Two programs – the Summer InTURnship Program and the Research Fellows Program – capitalize on the Institute's academic setting, by involving interested students in the application and research of toxics use reduction.

☐ Summer InTURnship Program

Started in 1996, the Institute's Student InTURnship Program places college students in toxics use reduction-focused, three-month jobs in industry. These internships give valuable industry experience to the students while providing Massachusetts companies with interns trained in toxics use reduction techniques.

Participating Companies

Acushnet Rubber Company, Inc., New Bedford - ISO 14001 Certification

K&M Electronics, Inc., West Springfield - HCFC Replacements for Deflux of Printed Wiring Boards

Adtec Electroplating, Lawrence - TUR Options Through Industrial Hygiene Audits

Raytheon Electronic Systems, Lexington - Compatibility of Solder Masks with Low-VOC Coatings

☐ Research Fellows Program

Since 1991, the Institute's Research Fellows Program has supported applied research at the University of Massachusetts Lowell that integrates toxics use reduction techniques into engineering, science, education, health sciences, management and policy research.

- Research Fellowships are awarded competitively to graduate students working with faculty.
- The Research Fellows Program supports research that is conducted in partnership with Massachusetts industry, relevant to Massachusetts manufacturers, and furthers the University's mission of enhancing the regional economy.

Selected Fellowship Projects

- Evaluation of Additive Technologies in the Printed Circuit Board Industry
- Development of PP/OASys (Pollution Prevention Options Assessment System) a spreadsheet-based decision making tool designed to assess and compare the environmental, worker and public health impacts of TUR options
- Closed Loop Aqueous Cleaning
- Evaluation of No-Clean Soldering in Printed Wiring Board Manufacturing

Toxics Use Reduction Science Advisory Board

In 1994 the Toxics Use Reduction Program established a special Science Advisory Board to advise the Institute on scientific issues. The legislation specifies that the Board review petitions to list or delist chemicals. The Institute performs research on issues important to the petitions and provides supplemental information to the Board in support of their deliberations.

- The Institute creates and maintains an active board of scientific experts with a broad base of knowledge in toxicology, epidemiology, occupational medicine, environmental science and chemistry.
- Fifteen petitions for chemical listing or delisting have been referred to the Board. To date, recommendations have been made for twelve petitions.

Chemicals Recommended by the Board:

for Delisting:

- nickel, chromium, copper, manganese, and cobalt - in alloy form, larger than 50 μm
- chromium (III) oxide
- hydroquinone, except for its manufacture
- butyl benzyl phthalate
- acetic acid - concentrations below 12%

to Remain on the List:

- sodium hydroxide
- ethyl acetate
- sodium hypochlorite

Sustainable Production Methods

The long term goal of toxics use reduction is to incorporate toxics use reduction principles into process and product design. Design decisions can often be complex, requiring an understanding of the potential environmental, human health and safety impacts of chemical and equipment choices. Massachusetts companies need methods and information to evaluate materials, products and processes in order to make environmentally sound decisions.

The Institute has developed or supported development of several methods to assist in integrating toxics use reduction into product and process design.

- PP/OASys (Pollution Prevention Options Assessment System) is a spreadsheet-based decision-making tool for small and medium-sized companies designed to assess and compare the environmental, worker and public health impacts of toxics use reduction options.
- Integration of toxics use reduction and design for the environment in the product design process at M/A-COM - Industry Matching Grant and toxics use reduction planner continuing education module
- Cleaner Technology Demonstration Sites/Industry Matching Grant to Lockheed Martin Defense Systems - Design for the Environment training workshops for design and process engineers

III. Summary of Research Work 1990 - 1997

Since its inception in 1990, the Institute has initiated a wide range of research projects in support of the objectives of the Toxics Use Reduction Act. The highlights of that work are summarized in this section. A list of publications, reports, and case studies published as a result of this work is included in the Appendix.

The Institute uses several different mechanisms to carry out its research work. Some work is performed directly by research staff, for example, testing conducted in the Surface Cleaning Laboratory, development of toxics use reduction options assessment methods, and literature research on innovative technologies. Other work is guided by the Institute and performed by industry, academia or consultants. For example, the Institute sponsors research in industry through its Matching Grants program, and in academia with the Research Fellows program. Results of research work are disseminated through a variety of means, including workshops and technical forums, published reports and fact sheets, and the Institute's Technology Transfer Center.

Surface Cleaning

The Institute has assisted many Massachusetts companies to identify safer cleaning alternatives. This has been accomplished through:

- *research, testing and evaluation in the Surface Cleaning Laboratory*
- *validation and demonstration with industry partners*
- *transfer of information through workshops and publications*

A. Surface Cleaning Laboratory

The Surface Cleaning Laboratory assists Massachusetts companies in their search for safer cleaning processes.

During the initial development of the research programs, the Institute sponsored a series of industry focus groups. Out of those meetings arose a consensus that one of the major areas of chemical use affecting the widest range of Massachusetts industries was chlorinated solvents used for cleaning surfaces. It also was clear that Massachusetts industry, while desiring to move away from solvent use, had little in the way of technical support which could point toward reasonable solutions. The research staff decided to

The Surface Cleaning Laboratory has provided testing and evaluation assistance to 40 companies since 1993.

establish the Surface Cleaning Laboratory (SCL) to address this need. With the assistance of generous equipment donations from Digital Equipment Corporation and Raytheon, the lab was opened in late 1993. Over its first three years of operation, laboratory assistance was provided to more than 40 Massachusetts companies and informational assistance was provided to more than 200 companies.

The SCL is a state-of-the-art laboratory with equipment for aqueous and semi-aqueous cleaning, rinsing and drying. The lab tests and evaluates cleaners and equipment and assists companies in selecting process-specific cleaning systems and solving their cleaning problems. The SCL is also able to measure cleanliness using a variety of analytical tools and helps companies define cleaning specifications for their processes.

B. Clean Alternatives Project

Three Massachusetts companies received special assistance in analyzing their cleaning problems and identifying and evaluating alternatives through the Clean Alternatives Project.

Funded by a \$140,000 grant from the Environmental Protection Agency's National Risk Management Research Laboratory, the Clean Alternatives Project consisted of technical, financial and substitution (environmental, health and safety) analyses of alternatives to chlorinated solvents used for metal degreasing. Three Massachusetts companies participated in this project. All three were at different stages of the conversion away from chlorinated solvent cleaning. Each situation offered different lessons about the success and applicability of alternative cleaning processes.

During the technical analysis, alternatives to the chlorinated solvents were identified, demonstrated and evaluated. Testing and evaluation was performed in the Surface Cleaning Laboratory prior to implementation of the new cleaning processes at the facilities. A total cost assessment methodology was used to perform the financial analyses of the alternative cleaning processes. A qualitative substitution analysis methodology was developed and used to evaluate the environmental, occupational, and public health effects of the alternative cleaning processes.

C. Vendor Survey Database for Cleaning Equipment and Chemistries

Many companies have used the Cleaning Vendor Database to identify suppliers of alternative cleaning equipment and chemistries.

The Institute initiated the first "Vendor Survey for Cleaning Equipment and Chemistries" in 1993; the third edition is scheduled for release in 1997. The database is a compilation of responses from a survey of cleaner and equipment vendors. It provides companies with a comprehensive list of suppliers of safer cleaning alternatives, as well as a description of their product lines. Response

from companies has indicated that the database is extremely useful for identifying and contacting potential vendors. Several enhancements will be incorporated into the next edition, including the addition of closed-loop aqueous equipment vendors. It will be available electronically and as a hard-copy report.

Industry Partnerships

The Institute leverages its resources and promotes adoption of innovative toxics use reduction techniques by partnering with industry.

D. Industry Matching Grants

Through the Industry Matching Grants Program Massachusetts companies compete for grants to develop and evaluate innovative toxics use reduction technologies and methods.

The Industry Matching Grants Program has been facilitating the development and use of toxics use reduction techniques by Massachusetts industries since 1992. The program has provided matching funds each year to Massachusetts companies who carry out pollution prevention projects that develop innovative technologies, use existing technologies in innovative manners, and develop information that is then transferred to other industries.

From 1992 through 1997, 23 projects were funded with awards totaling \$266,000. Altogether, 24 Massachusetts companies have participated in the program. Grants, ranging from \$3,200 to \$25,000, have supported research projects ranging from feasibility studies of potential toxics use reduction options to pilot testing and validation of new technologies. In 1996, the Industry Matching Grants Program was merged with the Cleaner Technology Demonstration Sites Program. This extends the range of projects to include the demonstration of in-place technologies. Information on the combined program is included in Section II.

A few selected projects are listed below. A complete list of projects is included in the Appendix.

- **Printed Circuit Corp., Woburn**
Reclamation of Nitric Acid from Solder Strip
- **Malden Mills, Lawrence**
Reduction of Acetic Acid Us in the Disperse Dying of Textiles
- **Raffi & Swanson, Inc., Wilmington**
Cleaning Alternatives for Adhesives and Coatings Process Reactors

- **Smith & Wesson, Springfield**
VOC Lacquer Replacement
- **M/A-COM, Inc., Lowell**
Toxics Use Reduction and Design
for the Environment in the
Electronics Industry
- **Texas Instruments, Inc., Attleboro**
Supercritical Fluid Extraction
Cleaner Evaluation

***For FY93 through FY97,
29 Matching Grant and
Demonstration Site projects were
funded at Massachusetts companies
with awards totaling \$350,000.***

E. Cleaner Technology Demonstration Sites

The Cleaner Technology Demonstration Sites Program promotes the adoption of innovative technologies by allowing individuals to observe and assess their value first-hand.

The Cleaner Technology Demonstration Sites Program was launched in 1995 to showcase selected innovative technologies. In 1995 and 1996, a total of 25 site visits were held at 5 facilities throughout the Commonwealth. Approximately 500 individuals representing industry, Toxics Use Reduction Planners, environmental groups, community groups and technical assistance agencies attended the site visits and observed. The program promotes adoption of innovative technologies by allowing individuals and firms to observe and assess their value first-hand. For example, as a result of attending a Cleaner Technology Demonstration Site visit, a metal parts manufacturer worked with the Surface Cleaning Lab and is now considering the implementation of one or more of the Lab's recommendations. At a site demonstrating electron beam curing technology, two textile companies had the opportunity to test samples of their fabrics. They are now investigating the feasibility of using that cleaner technology to replace their traditional thermally-cured systems.

A follow-up survey will be done with those who visited the sites to determine how many companies implement cleaner technologies as a result of their visits to the demonstration sites.

The first five projects were:

- **Cranston Print Works, Webster**
Toxics use reduction through process improvement, substitution, and integral recycling
- **Metallized Products, Inc., Winchester**
Electron beam curing of polymers in coating processes
- **Utopia Cleaners, Arlington**
Garment wet cleaning
- **Danaher Tool Group, Springfield**
Nitric acid recovery using diffusion dialysis

- **Lockheed Martin Defense Systems, Pittsfield**
Aqueous cleaning of mechanical parts
-

University Programs

The Institute collaborates with university faculty and students to perform research and provide assistance to companies. This collaboration has led to an understanding of pollution prevention and toxics use reduction by University faculty and students and has created the capacity for significant pollution prevention research at the University.

F. InTURn Program

The InTURn Program gives valuable industry experience to students while providing Massachusetts companies with interns trained in toxics use reduction.

The InTURn Program began in 1996 placing four students in three-month, toxics use reduction-related industry work assignments. Before joining their companies, the interns were trained in toxics use reduction techniques and policies by the Institute staff. All four internships were successful both for the companies and the students. Company sponsors were very positive about the capabilities of the students and the match between job descriptions and abilities. This summer, the program will target companies in the Lowell area to promote university-industry relations and to ease the commute for the students. The four 1996 projects were:

One intern's project aided Acushnet Rubber Company in attaining ISO 14001 certification

- **Acushnet Rubber Company, Inc.**, New Bedford, a manufacturer of rubber products sponsored a graduate student in environmental science to help Acushnet attain ISO 14001 certification and to identify opportunities for toxics use reduction in the ISO 14001 requirements.
- **K&M Electronics, Inc.**, West Springfield, a manufacturer of electronic supplies, sponsored a civil/environmental engineering student to identify and evaluate options to replace hydrochlorofluorocarbons used to deflux circuit board assemblies.
- **Adtec Electroplating**, Lawrence, an electroplating facility, received the assistance of a graduate student in industrial hygiene who identified toxics use reduction options through industrial hygiene audits.

- **Raytheon Electronic Systems**, Lexington, a manufacturer of commercial and government program electronic systems, defined a project to evaluate the compatibility of soldering masks with low-volatile organic compound conformal coatings for a graduate student in environmental engineering.

G. TURI Research Fellows Program

The Research Fellows Program has created capacity, both with faculty and students, for toxics use reduction and pollution prevention research. The result has been innovations in areas such as bio-polymers, printed wiring board manufacture, supercritical fluids and substitution analysis methodologies.

Since 1991, the Institute has awarded stipends to graduate students to assist them and their faculty advisors in conducting research on toxics use reduction projects. The students receiving stipends are designated as TURI Research Fellows and work interactively with both their departmental advisor and members of the Institute research staff. A total of 22 graduate students were supported in the six years of the program; these students were members of several different departments including Chemical Engineering, Mechanical Engineering, Industrial Technology, Chemistry, Work Environment, and Plastics Engineering.

The program has proven to be advantageous in several ways, beyond the obvious advantage to the students. The research performed has proven, in most cases, to be directly relevant to the Toxics Use Reduction Program. For example, many of the Institute's Technical, Methods and Policy Reports resulted directly from Research Fellows projects. An added but more indirect benefit has been the development of an awareness of the importance of toxics use reduction among the students and faculty in the various departments which have received awards. This has led to various faculty members obtaining other sources of funding to continue toxics use reduction research.

H. Pollution Prevention Problem Sets for Engineering Curriculum

Homework problems created under the Pollution Prevention Problem Sets Project integrated pollution prevention concepts into core engineering courses.

Introducing engineers of the future to the concepts, techniques and benefits of pollution prevention is a critical element in a strategy to promote environmental protection. While whole courses in pollution prevention at the undergraduate and graduate level are extremely valuable, they do not reach the majority of engineering students or faculty. Incorporating pollution prevention into core courses in engineering disciplines is essential.

Through a collaborative effort, the Institute and engineering faculty from the University of Massachusetts Lowell, University of Vermont, the University of New Hampshire, and Dartmouth College developed a book of quantitative homework problems for engineering subjects that illustrate pollution prevention. These homework problems can be incorporated into almost all major engineering disciplines, including chemical engineering, civil/environmental engineering, mechanical and materials processing engineering and industrial engineering. The problem book has been made available to colleges and universities throughout the New England region.

This effort was supported by a \$22,300 grant from the Pollution Prevention Consortium of New England Universities through the Northeast Environmental Security Training and Education Alliance.

I. Microscale Chemistry

Microscale chemistry makes high school, college, and industrial laboratories safer by reducing the volume of toxic chemicals stored, used and disposed of.

Microscale chemistry is a chemistry laboratory management system, pioneered at Merrimack College, which reduces dramatically the volume of chemicals used in chemistry laboratories. This reduction in chemical use reduces the potential for chemical exposure to laboratory personnel and reduces the volume of chemicals which must be disposed of as hazardous waste. Since 1993 the Institute has funded the National Microscale Chemistry Center at Merrimack College. Much of the work performed under this funding has consisted of conducting a series of workshops to train college and high school chemistry teachers and industry-based analytical chemists in the use of microscale techniques in organic and inorganic chemistry labs. In addition, microscale chemistry analytical equipment has been purchased in order to convert chemistry labs at the Lowell and Boston campuses of the University of Massachusetts to the microscale level.

J. Tufts University Capstone Projects

The Tufts University Capstone projects have made use of students trained in hazardous materials management to prepare industry sector studies for the Institute.

The Institute has acted as "client" for three Tufts University Hazardous Materials Management Program Capstone Projects. The Institute worked with the students to define the scope of the projects and provided assistance to the Capstone teams in their research efforts. The three projects were:

- Toxics Use in Biotechnology
- Toxics Use in Photovoltaic Manufacturing

- Environmental Issues Facing the Recording Industry (*Co-client with University of Massachusetts Lowell's Recording Industry Environmental Task Force*)
-

Policy and Methods Research

The Institute has performed research that is internationally recognized, in toxics use reduction and cleaner production policy. Methods and policy projects include the analysis of chemical restrictions policies, measuring progress in toxics use reduction, and the comprehensive program evaluation.

K. Chemical Restrictions Policies

Two major policy studies, mandated by TURA, were completed on the need for further chemical restrictions in the Commonwealth.

Institute research staff prepared two policy research reports for the Commonwealth considering the need for and feasibility of toxic chemical restriction policies that go beyond the mandates of the state Toxics Use Reduction Law. These reports examined the performance of other chemical use restriction policies such as "chemical bans", "chemical sunsets" and "chemical phase-outs" and concluded that the toxics use reduction program needed time to demonstrate its effectiveness and it would be premature to conclude that more aggressive state policies were warranted. The reports did recommend a systematic evaluation of twenty-one chemicals of widespread concern and their hazards, uses, costs and available alternatives.

The Chemical Restrictions study recommended a systematic evaluation of chemicals and their hazards, uses, costs and available alternatives.

L. Toxics Use Reduction Data Analysis

Analysis of the TURA data has helped to shape the Institute's priorities and provides feedback to the TURA Program, the public and industry on progress in toxics use reduction.

The Institute took the lead in a Toxics Use Reduction Program-wide effort to measure progress in toxics use reduction using the state Toxics Use Reduction data reported on Form 'S'. Assisted by a \$50,000 grant from the federal Environmental Protection Agency's Pollution Prevention Incentives for States program, the project achieved the following objectives:

- Improved the quality and useability of the state data

- Defined a methodology for measuring progress in toxics use reduction using available data
- Tested the methodology using available data
- Defined a methodology for establishing a 1987 baseline
- Conducted a "reality check" to evaluate the validity of the reported data

The Institute's primary role was to develop and test a methodology for measuring progress. The methodology includes actual changes in toxic chemical use, byproduct and other quantities, as well as changes normalized for level of production. The normalized quantity is a truer measure of actual toxics use reduction, because it factors out changes in chemical use and byproduct due to changes in production.

The Institute continues to analyze the reported data each year. For 1990 to 1995, the data shows a 19% actual reduction in byproduct generation, and a 30% normalized reduction for a consistent group of chemicals and industries. It also shows an 8% actual and a 20% normalized drop in total toxic chemical use.

M. Toxics Use Reduction Program Performance Evaluation

The Institute has taken principle responsibility for a comprehensive evaluation of the TURA Program.

The administering agencies of the Toxics Use Reduction Program have agreed to jointly administer a program performance evaluation that began in 1995. The evaluation is being spearheaded by the Institute research staff.

The goals of the program performance evaluation include (1) to fulfill the law's requirement that the program assess itself against the first goal of the Toxics Use Reduction Act: a 50% reduction in toxic waste by the year 1997; (2) to measure and assess the program's performance on the other five goals of the Act; (3) to inform the public and the Massachusetts Legislature about the effectiveness of the Toxics Use Reduction program; and (4) to enable program improvements based on evaluation data.

Components of the program performance currently in progress include the following:

- Mandates fulfillment analysis - an assessment of whether the Toxics Use Reduction agencies have fulfilled the specific mandates contained in the Act.
- State Toxics Use Reduction data analysis, including trend and sectoral analysis, data normalization and construction of a 1987 baseline to evaluate the program's achievements from 1987 to 1997.
- A telephone survey of firms complying with the Law designed to increase understanding of whether and how firms have implemented toxics use reduction, to identify associations

between program elements and toxics use reduction activities within firms and to guide the program in improvements. This survey was designed and implemented by a private consultant.

- An in-depth investigation of toxics use reduction activities in 25 Massachusetts firms.
- A cost/benefit study of the Toxics Use Reduction program.

The results of these program evaluation efforts will be released in a report in early 1997.

N. Science Advisory Board

The Science Advisory Board is a multi-disciplinary group of experts which advises the Institute on scientific issues, such as the listing and delisting of chemicals.

The Toxics Use Reduction Science Advisory Board held its first meeting in December 1994. The Board serves as the Institute's consultative group and has, thus far, been asked to review and make recommendations on petitions for additions and deletions from the Toxics Use Reduction Toxic or Hazardous Substance List.

The Science Advisory Board has made recommendations on twelve petitions. These recommendations are subsequently reviewed by the research staff for comment on the policy and financial implications. A recommendation regarding the petition is then made by the Institute to the Toxics Use Reduction Administrative Council for ruling. Due to the hard work and thoughtful deliberation of the Board, the Administrative Council has delisted the following chemicals: copper in alloy form, manganese in alloy form, nickel in alloy form, chromium in alloy form, cobalt in alloy form (particle size for alloys must be greater than 50 microns for delisting), chromium (III) oxide, hydroquinone except for the manufacture of hydroquinone and acetic acid (12% concentration or less). The Science Advisory Board recommended that sodium hydroxide, ethyl acetate and sodium hypochlorite remain on the list. Butyl benzyl phthalate was recommended for delisting by the Board in the absence of science to prove that butyl benzyl phthalate is estrogenic. The Institute acknowledged the Board's recommendation and recognized the inconclusiveness of the science. On the basis of the most protective public policy, the Institute recommended not delisting at this time.

O. Regulatory and Practical Issues in the Promotion of Toxics Use Reduction in Massachusetts

This study examined all federal and state requirements pertaining to toxic chemicals, identified barriers to the implementation of toxics use reduction and made recommendations for changes to current policies and regulations.

The Toxics Use Reduction Act requires that the Administrative Council conduct inventories of all federal and state laws or regulations and reporting requirements pertaining to toxic chemicals, wastes and emissions and seek to promote increased coordination in the enforcement of these laws and regulations and reporting requirements. This report is a preliminary study of the regulatory barriers to pollution prevention that may impede effective implementation of toxics use reduction at the level of the industrial firm. The report identifies and analyzes incentives, disincentives and opportunities for toxics use reduction and makes recommendations for adjustments to some current policies and regulations.

P. Directory of Toxics Use Reduction Research Programs

The Institute produced one of the nation's first directories of research centers focused on Pollution Prevention and Toxics Use Reduction.

In 1994 the Institute compiled a listing of national and international organizations that perform or sponsor toxics use reduction projects "Toxics Use Reduction Research Directory, 1992". The listing is limited to organizations whose findings are available publicly. Each entry includes a general description of the organization and the research projects performed or sponsored by them.

Q. Additional Policy Research

The Institute has undertaken a variety of policy research initiatives to promote toxics use reduction.

In the spirit of the Toxics Use Reduction Act, which was supported by both industry and environmentalists, the Institute has worked since its inception to promote collaborative relationships, in particular between industry and government. One outcome of this work is a report, "Models for Industry-Government Collaboration on Pollution Prevention", that identified new industry-government collaborative models. These models are divisible into three frameworks: 1) roundtables, networks, and advisory panels; 2) demonstration projects and partnerships; and 3) information dissemination.

To understand what leads to a successful planning program the Institute performed a survey of states -- California, Minnesota, New York, Oregon, and Washington -- that have implemented pollution prevention planning programs. Lessons learned from the survey include: value of early commencement, value of access to information and technical assistance, value of wide participation, and value of consulting services. The report is titled "Pollution Prevention and Waste Reduction Planning: A Quick Look at Initial State Experience".

■ Blanket Wash Technology Study

The Institute worked with the Environmental Protection Agency's Design for the Environment Project for the printing industry, including the direction of focus groups with printers and participation on the Use Cluster Subcommittee. One of the priority use clusters identified was lithographic blanket washes. As a result, the Institute performed an in-depth study to evaluate the performance, environmental, health and safety characteristics of fourteen low VOC blanket washes for sheet-fed offset lithographic printers. A final report on the project was published in January 1994.

U. Development and Testing of Biosurfactants in Metal Cleaning Applications

A highly innovative project for metal cleaning combined the bio-synthesis expertise of University faculty with the surface cleaning expertise of the Institute to develop and test an innovative biosurfactant.

Supported by a \$120,000 grant from the Environmental Protection Agency, Office of Pollution Prevention and Toxics, this project was a collaborative effort with other researchers at the University of Massachusetts Lowell. This one-year project developed, tested and laid out a plan for transferring a new technology in a new application--biosynthesized, biodegradable surfactant technology as a component of aqueous surface cleaning chemistries.

The Biodegradable Polymer Research Center team developed and scaled-up production of several biopolymer analogues in their laboratories on campus and at the Natick Army Research Labs. The Institute designed and carried-out the evaluation of the surfactants in its Surface Cleaning Laboratory and the results of the Institute's evaluations influenced the direction of the biopolymer development process at the Biodegradable Polymer Research Center. Finally, the Massachusetts Bioprocess Development Center designed an industrial scale production facility for the manufacture of the biosurfactants and evaluated the effect of production scale on production costs.

The results of this work led to a grant award from the National Science Foundation to the University to further the biopolymer synthesis and scale-up research.

V. Additional Technical Research Projects

Since its inception, the Institute has had a strong focus on technical research projects. They have ranged from industry- and process-focused studies which identify opportunities and innovative solutions, to chemical-focused studies which examine the hazards of the substance, as well as its uses and potential alternatives.

The Institute has performed and supported research in many technical areas. The results of this research have been disseminated through over 200 presentations, participation in scores of workshops and panels and more than fifty publications. The end result is that:

TURI has published more than fifty articles, reports, and case studies documenting the results of the various research programs.

- companies are informed about the toxic chemicals used in their processes
- companies are presented with evaluations of potential toxics use reduction options for their materials and processes
- lessons learned from research in one industry are transferred to different industries and facilities

Technical research has been conducted by Institute staff, and sponsored through many different programs, including the Industry Matching Grants and Research Fellows programs. In addition to the major technical research projects described previously in this summary, the following examples of technical research are of particular note:

- **Non-cyanide plating and surface finishing:** In response to a request made by industry representatives, the Institute prepared a "Non-Cyanide Plating Fact Sheet." The fact sheet presented alternatives to cyanide plating baths and listed advantages, disadvantages, and current and potential applications. In addition, two cyanide reduction projects were sponsored as Matching Grants: "Cyanide Reduction in Bright Stripping Using an Electrolytic Process" and "Cyanide-Based Electroplating Elimination."
- **Alternatives to solvent-based coatings:** A study of alternatives to solvent-based coatings resulted in another fact sheet. The fact sheets are used by companies as a first step in their search for safer alternatives.
- **Chemical use analyses:** These reports are a systematic analysis of use, toxicity, safety, and available alternatives, for a number of chemicals, including: cadmium, cyanide, methyl ethyl ketone, styrene, and trichloroethylene.

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APPENDIX

Matching Grants and Cleaner Technology Demonstration Sites FY97

For FY97, a total of \$60,000 has been awarded to support the following five projects.

Leach & Garner Company, General Findings Division, North Attleboro

Ammonia Reduction for Heat Treat Furnace Atmospheres

In order to reduce the amount of ammonia used to create a protective atmosphere in their heat-treat furnace, Leach & Garner will dilute the dissociated ammonia with nitrogen.

Expected benefits include cost savings and significant reductions in ammonia use.

Lockheed Martin Defense Systems, Pittsfield

Design for Environment (DfE) Workshops

Lockheed Martin will develop and present workshops to help design engineers integrate TUR and other environmental considerations into product and process design. The course will present examples of how to identify, screen and apply TUR techniques to reduce or eliminate toxics in the design-phase of a project.

Ocean Spray Cranberries, Inc., Middleboro

Elimination of Cooling Tower Chemical Additives

Ocean Spray will test and validate a technology to reduce TURA-listed chemicals used as corrosion inhibitors, pH adjusters, and biocides in cooling water. The technology uses a transformer that applies continuously changing frequencies to the fluid, resulting in the destruction of microbes, pH balance, and inhibited precipitation of scale in the fluid.

Parlex Corporation, Methuen

Innovations in Toxics Use Reduction in Printed Wiring Board Manufacture

Parlex Corporation will demonstrate:

- the use of a new "additive" silver screening technology to replace the conventional "subtractive" method of applying copper shielding.
- a direct metallization process used to make through-holes conductive using graphite in place of the older, more expensive, and more chemically-intensive copper plating technology.

Tri-Star Technologies Company, Inc., Methuen

Cupric Chloride Etch Regeneration

Tri-Star, a manufacturer of printed wiring boards, will install a divided cell, simultaneous regeneration system that uses an electrolytic technique to regenerate a cupric chloride etching solution while recovering the copper from the solution. This system will replace the traditional oxidation process which uses hydrogen peroxide and hydrochloric acid.

Cleaner Technology Demonstration Sites FY96

Cranston Print Works, Webster

Process Improvement, Substitution, & Integral Recycling

Cranston Print Works dyes, prints, and finishes textile fabrics made from a variety of fibers. Techniques for achieving TUR include control charting to track everything from process temperatures to chemical use; recovering acetic acid vapor, used to "age" azoic dyes on certain types of fabrics, through an integral recovery system; and using CO₂ injection as a substitute for acids to effectively neutralize the pH of wastewater.

Danaher Tool Group, Springfield

Nitric Acid Recovery Using Diffusion Dialysis

Danaher Tool Group electroplates nickel and chromium onto hand tools, using a rack to suspend the tool in the electroplating solution. In order to recover the nitric acid used in their rack stripping process, Danaher has installed a diffusion dialysis system, which allows clean acid to return to the process, while contaminants are separated out as a reject solution.

Lockheed Martin Defense Systems, Pittsfield

Aqueous Cleaning of Mechanical Parts

Lockheed Martin Defense Systems has moved toward the elimination of ozone depleting chemicals in the cleaning of mechanical parts prior to assembly. Using a closed-loop, ultrasonically-agitated cleaning and rinsing system, Lockheed disposes of spent aqueous solutions only once annually. Less than one half drum per year of waste oil is disposed of as a regulated waste.

Metallized Products, Inc., Winchester

Electron Beam Curing of Polymers in Coating Processes

Metallized Products, Inc. is a web coater that specializes in the electron beam curing of solvent-free 100% reactive coatings and inks. Products include printed and coated food packaging, shrink wrap, ready-to-assemble furniture, and silicone release liners for labels. Additional applications may include coatings on paper, plastics and textiles.

Utopia Cleaners, Arlington

Garment Wet Cleaning

Utopia Cleaners made the transition to perchloroethylene-free clothes cleaning by diverting a portion of its clothes stream to wet cleaning. Recently, a more advanced wet cleaning system allowed Utopia to significantly increase the percentage of clothes it wet cleans by reducing manual labor, shortening drying time, and simplifying the process.

**Matching Grants
FY96**

For FY96, a total of \$50,000 was awarded to support four projects.

Malden Mills Corporation, Lawrence

Reduction and Possible Elimination of Acetic Acid Use in the Disperse Dyeing of Textiles

The use of acetic acid in the disperse dyeing of polyester and polyamide textiles will be optimized and thereby reduced through the use of automated pH monitoring and acid injection. In addition, the use of CO₂ will be evaluated as a substitute for acetic acid for pH adjustment.

Raffi & Swanson, Inc., Wilmington

Cleaning Alternatives for Adhesives and Coatings Process Reactors

This project will evaluate alternatives to volatile organic solvents for the cleaning of coatings and adhesives reactor tanks. Bench and pilot scale tests will be performed to determine the effectiveness of various semi-aqueous and aqueous processes.

M/A-COM, Inc., Lowell

Toxics Use Reduction and Design for the Environment in the Electronics Industry

The long term goal of toxics use reduction is to incorporate these principles into product design. This project will follow the development of computerized life cycle assessment tools and a design guide which will consider TUR issues concurrently with other traditional design criteria.

Commonwealth Sprague Capacitor, Inc., North Adams

Aqueous Degreasing for Electronic Components Manufacturing

This company has worked with TURI's Surface Cleaning Laboratory to identify potential aqueous equipment and chemistries to replace trichloroethylene degreasing operations. This project will follow the implementation process through vendor trials, pilot testing and full installation.

**Matching Grants
FY95**

In FY 95, a total of \$35,000 was awarded to support the following three projects.

Dav-Tech Plating, Inc., Marlborough

Electrodialysis for Integral Recycling of Electroless Nickel Baths

An advanced electrodialysis process will be demonstrated for recycling of spent electroless nickel (EN) baths. The objective is to dramatically increase the useful bath life by separating contaminants, predominantly orthophosphite, from the hypophosphite-based EN solution. Assuming pilot tests are successful, the electrodialysis process will be hard-piped to the EN baths.

Printed Circuit Corporation, Woburn

Reclamation of Nitric Acid from Solder Strip

Diffusion dialysis will be used to integrally recycle a nitric acid-based solder strip during printed circuit board manufacture. The stripping solution, which also contains iron salts, will be separated from the stripped metals, which are principally tin and lead. The focus of the project will be to determine which components of the stripping solution are separated out, and therefore, which must be added back.

M/A-COM, Inc., Lowell

Integrating Design for the Environment and Toxics Use Reduction Principles into the R&D Process

The long-term goal of toxics use reduction is to incorporate these principles into the earliest stages of product design. This project will introduce environmental considerations into the R&D process by utilizing product/process inventory, life cycle analysis, and improvement analysis tools. Training around these concepts and tools will be provided to designers, and the effectiveness of the process will be evaluated.

**Industry Matching Grants
FY93 and FY94**

Closed-Loop Aqueous Cleaning Systems and Alternative Lubricants for Metal Forming

Bay State Skills Corporation, representing a consortium of six metal forming companies: A.J. Knott Tool & Mfr. Corp., Gillette Corp., Norwood Stamping Co., Metropolitan Machine Co., Larson Tool & Stamping Co. and HERFCO.

Alternative Equipment for Bulk Degreasing and Abrasive Blasting Operations

Beloit Fiber Systems, Dalton

Elimination of Ozone Depleting Chemicals

M/A-COM, Inc., Lowell

Alternatives to Arsine in Arsenic Ion Implantation

M/A-COM Semiconductor Products Division, Burlington

Elimination of Cyanide-Based Electroplating

Northrop, Electronics Systems Division, Norwood

Alternative Refrigerants for Industrial Chillers

Plastic Distributing Corporation, Ayer

Water-Based Polymer Coating to Replace Nickel Pentrate and Anodized Coatings

Smith & Wesson, Springfield

VOC Lacquer Replacement

Smith & Wesson, Springfield

Supercritical Fluid Extraction (SFE) Cleaner Evaluation

Texas Instruments, Inc., Materials and Controls Group, Attleboro

Reduction of Cyanide Use in Electrolytic Cyanide Stripping

The Robbins Company, Attleboro

Research Fellows

1996-1997 Research Fellows

Dennis Gagne, M.S. Candidate, Mechanical Engineering Department
Evaluation of Additive Technologies in the Printed Circuit Board Industry
Prof. Sammy Shina, Mechanical Engineering Department

Alexandra Gonzalez, Work Environment Department
Development and Testing of PP/OASys - the Pollution Prevention Options Assessment System
Prof. Mike Ellenbecker, Work Environment Department

Ramesh Sethuraman, M.S. Candidate, Environmental Engineering
Surface Cleaning Research
Prof. Mike Ellenbecker, Work Environment Department

1995-1996 Research Fellows

Doug Sommer, M.S. Candidate, Mechanical Engineering Department
Implementation of "No Clean" Solder for Ultra Fine Pitch Surface Mount Technology
Prof. Sammy Shina, Mechanical Engineering Department

Joel Tickner, Doctoral Candidate, Work Environment
Development of a practical, low-cost methodology to assess the environmental, worker and public health impacts of alternative technologies aimed at reducing toxic chemical use
Prof. David Kriebel, Work Environment Department

Chris Underwood, M.S. Candidate, Department of Chemical Engineering
"Closing the Loop", A Guide to the Recycling and Reuse of Aqueous Cleaners
Prof. Al Donatelli, Department of Chemical Engineering

1992-1995 Research Fellows

Beth Rosenberg, Sc.D. Candidate, Work Environment Department
Impact Analysis of Pesticide Bans
Prof. Charles Levenstein, Work Environment Department

Jennifer Penney, Sc.D. Candidate, Work Environment Department
Application of TUR Approaches to OSHA Policy
Prof. Rafael Moure-Eraso, Work Environment Department

Fu-Jung Kao, Ph.D Candidate, Polymer Science, Department of Chemistry
The Use of Supercritical Fluids as Substitutes for Dry Cleaning Solvents: Evaluation of Enzyme Activity for Stain Removal
Prof. Samuel P. Sawan, Department of Chemistry

Paul F. Hailey, M.S. Candidate, Manufacturing Engineering
"No-Clean" Soldering in Electronics Manufacturing
Prof. Sammy G. Shina, Mechanical Engineering Department

Michael Reinhardt, Doctor of Engineering Candidate, Mechanical Engineering
Design for Environment Metrics and Fuzzy Logic
Prof. John Duffy, Mechanical Engineering Department

Donald LaTourette, MS Candidate, Work Environment Department
TURA Data Analysis
Prof. Michael Ellenbecker, Work Environment Department

Chengchen Mao, Sc.D. Candidate, Work Environment Department
Proposal for Formaldehyde Use Reduction in Mortuaries and Anatomy Laboratories
Prof. Susan Woskie, Work Environment Department

Yeong-Tarn Shieh, Post Doctoral Scholar, Supercritical Fluids Laboratory, Dept of Chemistry
Jan-Hon Su, Research Associate, Supercritical Fluids Laboratory, Dept of Chemistry
Fu-Jung Kao, Ph.D. Candidate, Polymer Science, Department of Chemistry
The Use of Supercritical Fluids as Substitutes for Cleaning Solvents: Evaluation of the Interaction of Supercritical Carbon Dioxide and Cosolvents with Polymeric Materials and Adhesives
Prof. Samuel P. Sawan, Department of Chemistry

Kenneth Moore, Ph.D Candidate, Biochemistry
Venkataramani Shivshankar, Master's Degree Student, Chemical Engineering
Alec Crawford, Chemical Engineering
Non-Volatile Precursors To Olefinic Bromofluorocarbons [NVP-OBFC's] as Alternative Fire Extinguishing Agents with reduced Global Environmental Impacts
Prof. William W. Bannister and Edwin G.E. Jahngen, Department of Chemistry

Savvas Hadjikyriacou, Ph.D Candidate, Polymer Science
Solvent Use Reduction Technologies: Macromeric Surfactants in Emulsion Polymerization Systems
Prof. Rudolf Faust, Department of Chemistry

Feng Ying Shi, Ph.D. Candidate and Ann Marie Cromwick, Ph.D Candidate, Chemistry
**A Biological Process to make Environmentally Friendly Water Soluble Ionic Polymers:
Gamma poly (Glutamic Acid) Production and Isolation**
Prof. Richard A. Gross, Department of Chemistry

Chin-Long Wu , Ph.D. Candidate, Plastics Engineering
Mike Dango, Master's Degree Student, Dept. of Chemical and Nuclear Engineering
Devon Genus, Department of Chemical Engineering
**Biological Synthesis of Chemicals and Materials: Biological Synthesis of 4,5-dihydroxy-
4,5-dihydrophthalate as an Intermediate to Para Polyphthalene**
Prof. Carl W. Lawton, Department of Chemical Engineering

Frances A. Eagle, Doctor of Engineering program, Plastics Engineering
Life Cycle Analysis: Petrochemical Synthesis Versus Biological Synthesis of Polymers
Prof. Stephen McCarthy, Plastics Engineering Department

Steve Mullin, Master's Degree Student, Chemical Engineering
Synthesis of Silicon Carbide Fibers
Prof. Joseph Milstein, Electrical Engineering Department and
Prof. Thomas Vasilos, Chemical and Nuclear Engineering Department

Research Publications

Technical Fact Sheets

4 Non-Cyanide Plating Processes

5 Alternatives to Solvent-Based Coatings

6 Alternatives to Petroleum and Solvent-Based Inks

Article Reprints

"Toxics Use Reduction and Pollution Prevention," *New Solutions*, Spring, 1990.

"Techniques in Toxics Use Reduction: From Concept to Action," *New Solutions*, Fall 1991.

"The Greening of Industry: Making the Transition to a Sustainable Economy," *Technology Review*, August/September 1991.

"Preventing Pollution: Promoting Safe Materials and Clean Technologies," *Toxics Times*, Fall 1991.

"Protecting Reproductive Health and the Environment: Toxics Use Reduction," *Environmental Health Perspectives Supplements*, 1993.

"Rediscovering Materials Policy," *Rethinking the Materials We Use*, World Wildlife Fund, 1993.

"A Proposal for Managing Chemical Restrictions at the State Level," *Pollution Prevention Review*, Spring 1994.

"Toxic Chemical Restrictions: Notes from Dialogues with Key Players," *New Solutions*, Summer 1994.

"Engineering Controls as an Intervention to Reduce Worker Exposure," *American Journal of Industrial Medicine*, 1996.

Technical Reports

1 *Toxics Use Reduction from Product Inception: Naturally Derived γ -Poly (Glutamic Acid)* 1992.

2 *Biological Synthesis of Chemicals and Materials: Production of Substituted Para-Polyphenylene*, 1992.

3 *Supercritical Carbon Dioxide as a Cleaning Solvent*, 1992.

4 *Substitution Case Study: Alternatives to Solvent-Based Paints*, 1993.

5 *Substitution Case Study: Alternatives to Solvent and Petroleum-Based Inks*, 1993.

6 *Health and Safety Impacts of Citrus-Based Terpenes in Printed Circuit Board Cleaning*, 1993.

7 *Styrene Use in Massachusetts*, 1993.

8 *Arsine Source Replacement for the Growth of Gallium Arsenide via MOCVD*, 1993.

9 *Elimination of Ozone Depleting Chemicals at M/A-COM, Inc.*, 1993.

11 *Alternative Fire Extinguishing Agents: Non-Volatile Precursors to Olefinic Bromofluorocarbons*, 1993.

12 *Supercritical Carbon Dioxide as a Cleaning Solvent: Evaluation of the Interaction with Polymeric Materials*, 1993.

13 *Solvent Reduction Technologies: Macromeric Surfactants in Emulsion Polymerization*, 1993.

14 *A Biological Process to Make Water Soluble Ionic Polymers: γ -Poly (Glutamic Acid) Production and Isolation*, 1993.

15 *Vendor Survey Database for Industrial Cleaning, 2nd Edition*, 1995.

16 *Blanket Wash Technology Study: An Evaluation of Commercially Available Blanket Washes*, 1994.

17 *Synthesis of Silicon Carbide Fibers*, 1993.

18 *Cyanide Reduction in Bright Stripping Using an Electrolytic Process: The Robbins Company*, 1994.

19 *VOC Lacquer Replacement For Wood Finishing*, Smith & Wesson, 1994.

20 *Cyanide-Based Electroplating Elimination: Northrup Grumman Corporation*, 1994.

21 *Supercritical Fluid Extraction Cleaner Application: Texas Instruments, Inc.*, 1994.

22 *Alternative Equipment for Bulk Degreasing and Abrasive Operations: Beloit Fiber Systems*, 1994.

23 *Alternative Fire Extinguishing Agents: Non-Volatile Precursors to Olefinic Bromofluorocarbons*, Final Report, 1994.

24 *Formaldehyde Use Reduction in Mortuaries*, 1994.

26 *Reclamation of Nitric Acid from Solder Strip*, Printed Circuit Corporation, 1995.

28 *Supercritical Fluids As Substitutes for Dry Cleaning Solvents: Evaluation of Enzyme Activity for Stain Removal*, 1995.

29 *Closed Loop Aqueous Cleaning*, 1995.

30 *Measuring Progress In Toxics Use Reduction and Pollution Prevention: Massachusetts Toxics Use Reduction Program*, 1995.

31 *Toxics Use Reduction Through Process Improvement, Substitution & Integral Recycling*, Cranston Print Works, 1996.

32 *Nitric Acid Recovery Using Diffusion Dialysis*, Danaher Tool Group, 1996.

33 *N-Methyl Pyrrolidone: Chemical Profile*, 1996.

Methods and Policy Reports

1 *Pollution Prevention and Waste Reduction Planning: A Quick Look at Initial State Experience*, 1992.

2 *Toxic Chemical Management in Massachusetts: An Analysis of Further Chemical Restriction Policies*, 1993.

3 *Models for Industry-Government Collaboration on Pollution Prevention*, 1993.

4 *A Background Document On Lifecycle Analysis: Biodegradable Polymers*, 1993.

5 *Summary of Responses: TURI Further Chemical Restrictions Policies*, 1993.

6 *The Cost of Changing: Total Cost Assessment of Solvent Alternatives*, 1994.

7 *Regulatory and Practical Issues In the Promotion of Toxics Use Reduction in Massachusetts*, 1994.

8 *The Role of Risk in Chemical Substitution Decisions*, 1994.

12 *Application of Toxics Use Reduction to OSHA Policy & Programs*, 1995.

13 *Unintended Consequences: Impacts of Pesticide Bans on Industry Workers, the Public, and the Environment*, 1995.

Cleaner Technology Demonstration Sites

TUR Through Process Improvement, Substitution and Integral Recycling, Cranston Print Works, 1996.

Nitric Acid Recovery Using Diffusion Dialysis, Danaher Tool Group, 1996.

Closed Loop Aqueous Cleaning of Mechanical Parts, Lockheed Martin Defense Systems, 1996.

Electron Beam Curing of Polymers in Coating Processes, Metallized Products, Inc., 1996.

Garment Wet Cleaning, Utopia Cleaners, 1996.

Surface Cleaning Case Studies and Fact Sheets

Case Studies

Market Forge, 1995

Wyman/Gordon Company, Inc. 1995

A. W. Chesterton, Inc., 1995

Osmun Music Company 1995

Fact Sheets

Surface Cleaning, 1996

HCFCs and Cleaning, 1996



November 25th, 1996

Surface Cleaning Laboratory (SCL) Project List

Client/Completion status	Project Description	Project Results
Electronics Company Project Completed	A manufacturer of gold-plated aluminum electrical components was looking for alternatives to Genesolve 2004 used in a vapor degreaser to remove flux, particles and fingerprints from their parts.	Client tried a no-clean flux which failed in house. The lab tested out several chemistries to use with ultrasonics. The client switched to ultrasonics but used a different chemistry than the lab recommended.
Stamping Company Project Completed	A manufacturer of copper tubes (6 in. long with 0.25 in. diameter, drawn at one end) that are used to regulate temperature in household hot water heaters was searching for alternatives to TCE used to remove a lard-based stamping fluid from their parts.	The SCL conducted tests that proved that copper tubes could be effectively cleaned with aqueous cleaning. Pointed out client to several vendors that would have equipment that was appropriate for their needs. Client purchased equipment last summer.
Adhesives Manufacturer Project Completed	A manufacturer of epoxy resins and curing agents was searching for an alternative to methanol, xylene and MEK to clean these adhesives from tooling equipment such as mixing blades and transfer couplings.	After testing out several aqueous chemistries in the lab, the SCL recommended chemistries and equipment to the client which were successfully put on-line. The SCL's work on this project was published in Case study No. 3.
Pump Manufacturer Project Completed	A manufacturer of stainless steel pumps and seals was not satisfied with their aqueous cleaning process that removed cutting oils and metal fines from their parts.	After evaluating the client's parts and process, the SCL found flaws in their machining and cleaning operations that caused their cleaning problems. Client has implemented the SCL's recommendations and are quite pleased with the results.

SCL Project List

Machinery Manufacturer Undergoing Implementation	A manufacturer of large machinery for the paper industry was searching for an alternative to their aqueous product used to remove cutting oils and rust preventatives from their products prior to final painting. The aqueous product was not effective and also had a quite high VOC content.	The SCL tested several aqueous cleaners and found two that drastically outperformed the client's current chemical. Client obtained samples from the chemical companies in September. Waiting for them to try product in plant; evaluation on hold due to busy production schedule.
Aircraft Parts Manufacturer Project Completed	A manufacturer of aircraft components was looking for a replacement for mineral spirits and a aqueous cleaner used to remove lapping oils from aluminum parts. The company previously tested several aqueous products that did not meet their quality specifications.	The SCL tested several aqueous cleaners and recommended one cleaning chemistry along with a two-stage rinsing process. Company switched to SCL's recommended process within one month and is very pleased with its performance.
Water Treatment Company Project Terminated	Local company that produces catalytic water treatment equipment was looking to see if their product would enhance either cleaning efficiency of aqueous solutions or bath life.	The SCL ran a series of tests for client and obtained inconclusive results. Due to lack of potential as an effective cleaning system, this project was stopped.
Capacitor Manufacturer Project Completed	A manufacturer of tin-plated can and lid capacitors was searching for an alternative to TCE vapor degreasing to remove various metalworking fluids from their product.	After SCL testing of viable aqueous cleaners, the client became a matching grants project. Client's work will soon be published in a case study.
Medical Device Manufacturer Project Terminated	A manufacturer of medical devices was searching for an alternative to CFC-113 used in a vapor degreaser to remove mold release agents, oils and fingerprints from their parts.	Testing was performed in that lab but due to client problems not related to the SCL, this project was terminated.

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Biomedical Device Manufacturer Still in testing phase	A manufacturer of biomedical parts was searching for alternatives to HCFC-141b used in a vapor degreaser to clean light oil and particles from their parts. Client was interested in evaluating the cleanliness level of parts cleaned in different systems at their facilities.	The SCL has been analyzing parts from client as they arrive for the past 3 months using OSEE and FTIR. Results are somewhat mixed. Some parts are cleaned better by the HCFC-141b while others are cleaned better by their alternative process. Project is ongoing.
Electronics Manufacturer Still in Testing Phase	A manufacturer of military radar electronics is searching for an alternative to 1,1,1 TCA used in a vapor degreaser to clean flux from circuit boards in accordance to Mil STD 2000. Client has already switched to aqueous for commercial products but the military parts are far too large and complex for aqueous cleaning to be effective.	SCL met with client in early November for the first time. Aqueous cleaning will not be appropriate for this application, so the SCL is focusing it's attention to finding the safest, most effective solvent replacement. Some chemicals under consideration are an IPA/cyclohexane mixture, HCFC-225, PCBTF and HFES.
Ornament Company Still in testing phase	A manufacturer of Christmas ornaments is searching for an alternative for TCE vapor degreasing to clean buffing compounds from their parts prior to a photo resist laminate. Client has been talking to several equipment vendors for the past year with no success.	SCL has begun testing of eight aqueous chemicals in lab with some very positive results. The SCL is currently waiting for client to send out more sample parts to conclude testing and make final recommendations. This may take a few months since the client has a large Christmas production backlog.
Manufacturer E-Beam Equipment Undergoing Implementation	A manufacturer of E-Beam curing equipment was committing MWRA permit violations for pH and copper content due to the acidic aqueous chemical used to remove oils and oxides from copper grids. Client called both SCL and OTA to solve this problem in order to comply with regulations and avoid fines.	The Client has used recommendations from both the OTA and SCL to remain within their permit limits. Some of these recommendations included fitting the cleaning sinks with screens to sieve out copper fines and also switching to a neutral aqueous cleaner that effectively removed oils and oxides while keeping copper base metal attack to a minimum.
Paper Mill Undergoing Implementation	A manufacturer of recycled tissue paper was looking for an alternative to a hydrocarbon chemical that was used to clean "stickies" from drying felts. Client was having very high VOC emissions from their current chemical and were facing fines from the DEP and EPA.	Client is currently testing chemicals in their facilities, based on SCL evaluations.

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Electronics Manufacturer Undergoing Implementation	A manufacturer of electronic components was looking for an alternative to Genesolve 2004 used in a vapor degreaser to remove fluxes from their parts.	SCL tested several different aqueous cleaners with some positive results. Following lab tests, the client hired a TURI summer intern to implement some of the lab testing. The client is still unable to switch out of Genesolve 2004 for some products, but most products are now cleaned with aqueous systems.
Machine Shop Still in Testing Phase	A manufacturer of metal products for various industries was looking for an alternative to perchloroethylene vapor degreasing to remove various cutting fluids and metal fines from its products.	Lab testing was completed in November and report sent out to client. Waiting on client's input to see where they would like to proceed next.
Plastic Manufacturer Undergoing Implementation	A manufacturer of injection-molded plastic parts was searching for a replacement for 1,1,1 TCA used in a wipe-down process to clean debris from their injection molding presses.	Due to the nature of the cleaning application, aqueous cleaning would not be effective. Several non-aqueous alternatives were evaluated and are currently being tested at the client's facilities. Some of the alternative being considered are isopropanol, propylene glycol monomethyl ether and 2-butoxyethanol.
Recycling Company Undergoing Implementation	A recycler of copper windings was looking for an alternative to a time-consuming manual operation to remove low level PCB asphalt from their parts prior to melting and recycling.	The SCL tested several semi-aqueous products for this particularly tough cleaning job. The lab found a soy-based ester coupled with a surfactant that showed very promising results. This chemical currently is being trialed by the client in a rotary spray washer with the vendor.
Plating Job Shop Project Completed	A plating job shop was looking for an alternative to Genesolve 2004 used in a vapor degreaser to remove oils, greases and waxes from a variety of substrates.	The SCL recommended a few aqueous chemistries that were effective in the lab and suggested certain equipment. The client went with a chemistry not recommended by the lab and has had problems with etching on some parts.

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Silversmith Undergoing Implementation	A silversmith was searching for an alternative to TCE used in a vapor degreaser to remove tripoli buffing compounds from their products. Although client had partially switched to aqueous cleaning, they were not satisfied with the aqueous system.	The SCL solved the problems with the current aqueous system by replacing chemistry suggested by the SCL. Due to the nature of their parts, it seems unlikely that client will totally switch to aqueous cleaning.
Precision Instrument Manufacturer Undergoing Implementation	A manufacture of precision pressure sensors was looking to improve the effectiveness of their current aqueous cleaning system. The client was also interested in establishing a benchmark cleanliness for its customers.	The SCL evaluated several different chemistries in lab that client is currently trying out at their facility. The SCL also used FTIR to evaluate different cleaning methods used at the client's facility.
Bicycle Manufacturer Project Completed	A manufacturer of titanium bicycle frames was looking for an alternative to TCE vapor degreasing to clean light oils form their parts. Client already planned to switch to aqueous cleaning and asked the SCL to verify that the new aqueous process would perform as well as their vapor degreaser.	SCL sample cleaned some parts in the lab and evaluated them to find that the aqueous cleaning worked better than the vapor degreaser. Client switched to the aqueous system and is satisfied with the results
Electro-Optical Devices- Project Completed	A manufacture of electro-optical devices was looking to improve their current aqueous cleaning process that removed stacking wax from soda-lime glass lenses.	The SCL found that their current cleaning process was good, but the contamination was occurring in their rinse water. Company resolved this rinsing issue and achieved acceptable cleanliness levels
Adhesive Manufacturer Project Completed	A manufacturer of adhesives was searching for an alternative for a heptane and toluene mixture used in a manual process to remove adhesives from processing equipment.	Several aqueous, semi-aqueous and solvents were tested in the lab. The SCL recommended a propasol solvent that was implemented at the client's facilities.
Boiling Plate Manufacturer Project Completed	A boiling plate manufacturer was searching for an alternative to a petroleum distillate used in a vapor degreaser to remove oils from aluminum and carbon steel boiler plates.	SCL work is documented in Case Study No. 1. Although the company had switched to aqueous cleaning a year ago, they occasionally are having problems with the new system.

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Manufacturer of Steel Collar Clamps Undergoing Implementation	Manufacturer of steel clamp collars who switched to aqueous cleaning was having problems with their heat treatment process after cleaning and wanted to find out if the cleaning method was a contributing cause.	Parts obtained from the client were evaluated and no organic contamination was detected. After further testing in the lab it seemed that the client's problem was due to detergent residue left from their current cleaning process.
Maker of Plastic Switches Project Stalled	A manufacturer of plastic electrical switches was searching for an alternative to isopropanol to clean light oils and dirt from plastic switch parts prior to ink stamping due to flammability concerns	Two different solutions were proposed by the SCL. The first entailed changing the current machinery to use aqueous cleaning. The second involved lowering the temperature in the curing section to below the autoignition temperature and increasing the curing time. The client has not acted on either solution to date.
Adhesives Manufacturer Project Stalled	A manufacturer of adhesives was searching for a replacement for MEK used in a soak tank to remove adhesives from contaminated mixing blades.	After extensive testing at the SCL, an aqueous chemical and appropriate equipment were recommended to company. As of last contact, the company has not switched due to lack of support from engineering and management.
Vessel Cleaning Company Project Completed	A company that cleans dirty chemical transport vessels was looking for alternatives to methylene chloride used for two different cleaning applications. The first was removing adhesive labels from large stainless steel totes, while the other was removing carbon black from 55 gallon drums.	The SCL evaluated sodium bicarbonate blasting to remove the adhesive labels. The client was very pleased with the cleaning results but opted not to use the blasting process due to the amount of noise created. The SCL tested ultrasonics on a chemistry supplied by the client to remove the carbon black and was successful. Client used this information to purchase drop-in transducers to clean the drums.
Ceramic Coating Company Undergoing Implementation	A company that coats ceramic parts was searching for an alternative to their manual cleaning process that removed a baked-on clay slurry from support screens without damaging them. Company was primarily interested in using ultrasonics for this process.	SCL tested out several chemistries in ultrasonics with mixed results. It was determined that ultrasonics could be used to clean the parts, but this would not be feasible economically. The SCL suggested that the company go with sodium bicarbonate blasting; at last contact, they were considering this approach.

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Musical Instrument Refinisher Project Completed	A refurbisher of musical instruments was searching for a replacement for TCE vapor degreasing to clean various oils, greases and lapping compounds from their parts.	The SCL found an aqueous chemistry that worked very well. Our company contact left the company to start his own business. The worked that the SCL performed was then used at the contact's business but was never implemented at the original client's site.
Electronics Manufacturer Project Completed	A manufacturer of receiver and radar components was looking for an alternative to methylene chloride vapor degreasing to remove fluxes and conformal coatings from PCB's.	After testing, the SCL recommended that the client separate its parts and clean the parts with the conformal coating in the vapor degreaser while cleaning the parts with the flux in an aqueous system. The client opted to switch it's vapor degreaser over to a two solvent system using Axarel and IPA.
Adhesives Manufacturer Project Completed	Client came to the lab to find a replacement for NMP and toluene used to clean adhesive residues from 1500 gallon reactors.	Project was turned into a matching grants project and will soon be a lab case study.
Chemical Company Project Terminated	A local chemical company came to the lab in hopes of testing out their new cleaning product. Their product was a soybean derived methyl ester. They were looking at ways to make their product more convenient to use.	Lab ran some cleaning tests that showed that this solvent would be excellent for applications where aqueous cleaners may not work. The one problem was that the product needed to be solvent rinsed. The client had some ideas on how to make this product water rinseable, but the SCL deemed these methods unrealistic and the project was terminated.
Metal Wire Manufacturer Project Completed	A manufacturer of refrigeration coils was searching for an alternative to perchloroethylene and methylene chloride used in a vapor degreaser to remove forming oils from their parts.	The SCL led the company to switch to a water-based forming fluid to make aqueous cleaning possible. Several chemistries were also tested to see their effectiveness on the water-soluble oil.
Forging Operations Project Completed	A forging operation was searching for an alternative to using glycol ether and potassium hydroxide to remove exhaust smut from aluminum ionizer plates.	The SCL evaluated several different aqueous cleaners and equipment pieces. The completed work was published in Case Study No.2.

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Lapping Job Shop Project Completed	A lapping job shop was searching for an alternative to TCA and TCE used in a vapor degreaser to remove a silicon carbide lapping oil from various parts.	The SCL tested a few chemistries with ultrasonics which were quite effective. The client was then directed to vendors and purchased the appropriate equipment and is now using aqueous cleaning.
Defense Contractor Future Project	A local defense manufacturer is looking for alternatives to passivation in treating stainless steel parts used for missile components. Looking to rewrite the old military spec with new process.	Will have more information on this proposed project in December.
Consulting Firm Future Project	A local consulting firm is interested in performing research on rinsing treating chemicals used in bare-board electronics manufacturing. Their goal is to find diffusion rates of these contaminants into water so that they can reduce rinsewater usage.	Company will be looking for EPA grant money in the next few months before the SCL considers undertaking this project.

SCL Client Names

Alpha Industries, Inc.	Fraen Corporation	Munters Cargocaire
Astron Inc.	The Gillette Company	Osmun Brass
A.W. Chesterton	Global Recycling Co., Inc.	Radar Technology, Inc.
Beloit Fiber Systems	ITW Devcon	Raffi & Swanson, Inc.
Berkshire Industries	K & M Electronics, Inc.	Redux Technologies
BlueStar Technologies	Light Metal Platers, Inc.	Simplex Time Recorder
C&K Components Inc.	Lunt Silversmiths	Springfield Wire
The Cadmus Group	Market Forge	Stafford Manufacturing
Commonwealth Sprague Capacitor	MKS Instruments	Stick-II Products
CR Bard Inc.	Merlin Bicycles	Textron Systems Division
Data Con, Inc.	MicroE	The Trilap Co., Inc.
Eastern Reproduction Corp.	Milestone Inc.	Wyman Gordon Company, Inc.
Energy Sciences Inc.	ModuForm Inc.	
Erving Paper		

